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APPLICATION OF NEW PROCESS TECHNOLOGY TO THE MANUFACTURE OF HOT-WOUND SPRINGS

U.S. ARMY WEAPONS COMMAND

TECHNICAL REPORT

Samuel L. Williams

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RESEARCH DIRECTORATE

WEAPONS LABORATORY USAWECOM

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ABSTRACT

The feasibility of using induction heating and concomitant quenching for hot winding large helical springs was established by the Research Directorate, Weapons Laboratory, WECOM. A full-scale experimental system was assembled, and M140 gun mount counterrecoil springs were coiled from three different materials. Springs with proper load-carrying capacity were produced from each of the materials.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the support of the Rock Island Arsenal Fabrication Branch, Foundry and Pattern Making Section, particularly Mr. Phil Hines and Mr. Lanny Ross whose suggestions were instrumental to the completion of the project.

Acknowledgment is equally extended to Headquarters and Installation Support Activity, Plant Utilities Branch, Electrical Section, and Mr. Tony Werthmann for the suggested electrical modifications to the hot winding system.

INTRODUCTION

This project was centered upon the investigation and evaluation of possible methods to upgrade current technology of hot-wound spring manufacture. Primarily, the project was directed toward the use of high-frequency induction heating methods and, subsequently, effort was also directed toward concomitant sequential quenching during hot winding.

The counterrecoil spring of the M140 gun mount was selected as a representative for testing the heating and quenching concepts. This spring has an outside diameter of approximately 13-1/2 inches and free height of 45 inches, made of 1 inch diameter wire (Dwg F8671112, Appendix A and Figure 1). The spring must pass the stringent Class A spring requirements of Specification MIL-S-13572, which includes presetting to solid height a minimum of five consecutive cycles with no more than 0.002 in/in loss in free height (Figures 1-3). The spring must also exert a force of approximately 3000 pounds when compressed to 22-1/2-inch operating height (Figure 2).

Three materials were selected for test: (1) the then current 9262-H steel called for by the drawing, (2) a previous drawing material, 5160-H steel, and (3) a new material being used in the spring application, 250-Grade maraging steel. Only very small quantities of the 9262-H steel and the marage material (other than entire steel mill heats) were available. All preliminary work on the project, therefore, was with the 5160-H material.

Preliminary concepts were to pass the approximately 27-foot length of 1-inch wire through an induction coil and directly onto the rotating mandrel. Either the coil and wire could traverse to produce a helical spring or the mandrel could traverse. The former, with a rotating but fixed-axis-line mandrel was more readily adopted to the available equipment.

DISCUSSION

System Development

Procurement cost of a completed commercial hot-winding system was estimated to be from $400,000 to $500,000, which was well beyond the funds extended for the project. The application of induction heating and in-line quenching

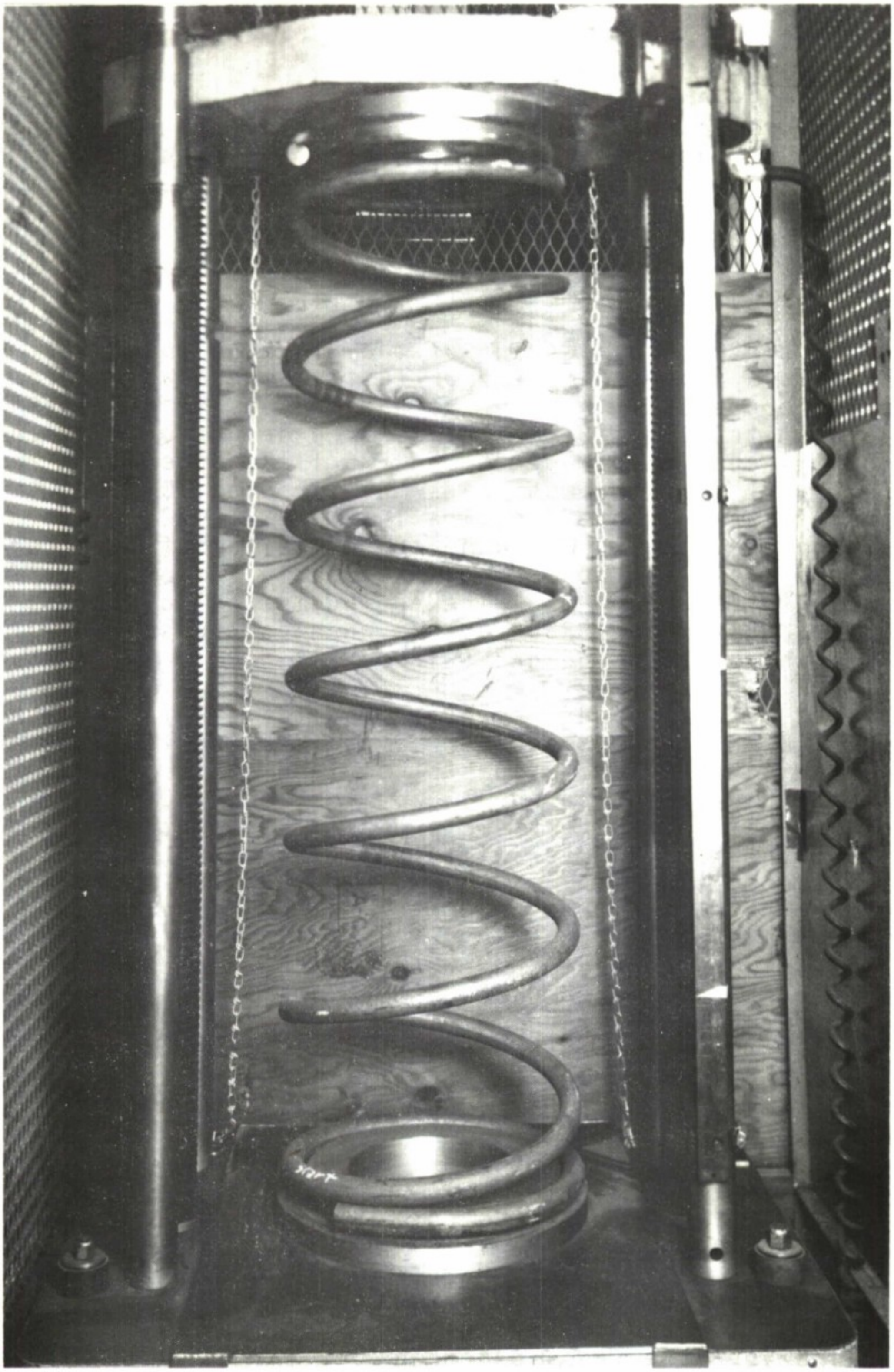


FIGURE 1 Spring F at Free Height in a Universal Test Machine (11-199-1317/AMC-72)

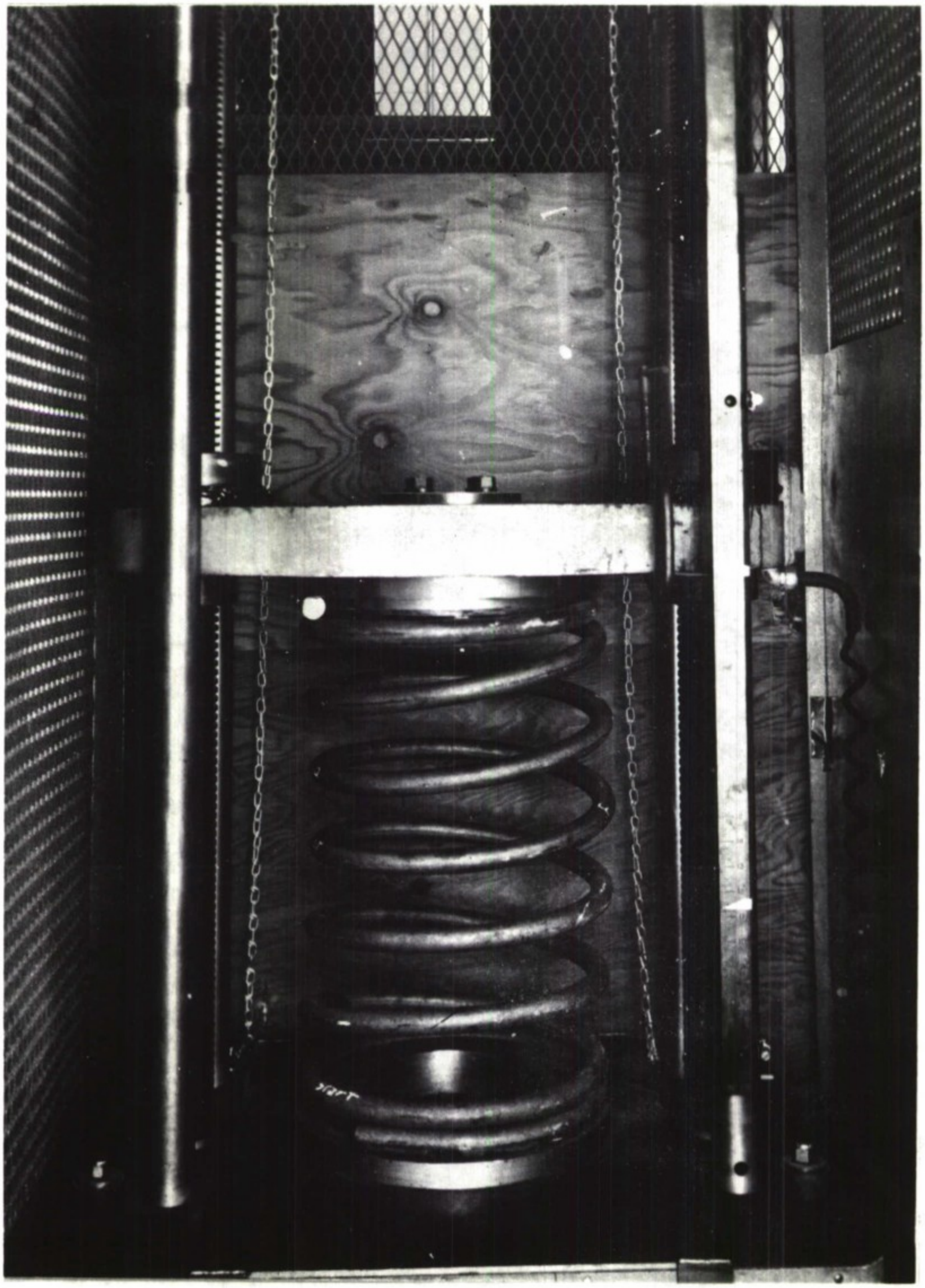


FIGURE 2 Spring F Compressed to Operating Height of 22-1/2 Inches. Average Load on Last Five Cycles was 3030 Pounds; Loss in Free Height was from 47-9/16 Inch to 47-1/2 Inches.
(11-199-1318/AMC-72)

FIGURE 3 Spring F Compressed to Approximate Solid Height. Average Load was 5370 Pounds. (11-199-1320/AMC-72)

while winding, however, could be developed and tested full scale by modification of on-hand equipment. The resultant system would be cumbrous and not applicable to production, but it would show the feasibility of the system.

A large belt-driven lathe was modified with a 7-1/2-horsepower, 1750 max. RPM, D.C., motor and a 20 to 1 gear box. The gear ratio of the lathe yielded a final ratio of 280 to 1 from the motor to a mandrel on the lathe. The modified lathe was placed near a 150 kilowatt, 9720 Hertz induction heating unit. Auxiliary controls for the motor speed, the temperature in the induction coil, and subsequently for the quenchant were breadboarded on a furnace control panel, and moved to the proximity of the lathe and the induction unit.

Original concepts of the winding system embodied the use of water-cooled cables to connect the high-amperage output of the induction heater to the induction coil which was bracketed to the lathe feed. Over forty combinations of transformer ratios (from 9:1 to 5:1) and capacitors (300 KVA rated) were used with over a dozen different coils, yet no combination succeeded in heating the 1-inch bar within a time frame suitable for hot winding. Experience had shown that 150 KW was more than sufficient to heat the bar; the power loss in the high amp cables was too great.

The heating problem was finally solved by moving the transformer and capacitor bank of the induction unit to the bracket with the coil, i.e., to the lathe feed and thereby the power loss in the cables was eliminated. The final lathe and coil modifications are shown in Figure 4.

The 1-inch wire extends to the left of the control panel in the figure. The left control panel contains the temperature indication and set hands, and the switches for power, motor, speed, and heat (Figure 5). The major components are labeled in Figure 4. Figure 6 illustrates the final position of the induction coil after a spring was hot-wound (although no spring is shown on the mandrel). The induction coil and the temperature monitoring radiation pyrometer are shown at close range in Figure 7.

After several springs were hot-wound on the system shown in Figures 4, 5, 6, and 7, a quench mechanism was added to the system. As shown in Figures 8 and 9, the major quench components were (1) a large reservoir tank of 100 gallon capacity, (2) a small bath tank around the mandrel, and (3) a low-pressure spray nozzle (Figure 9).

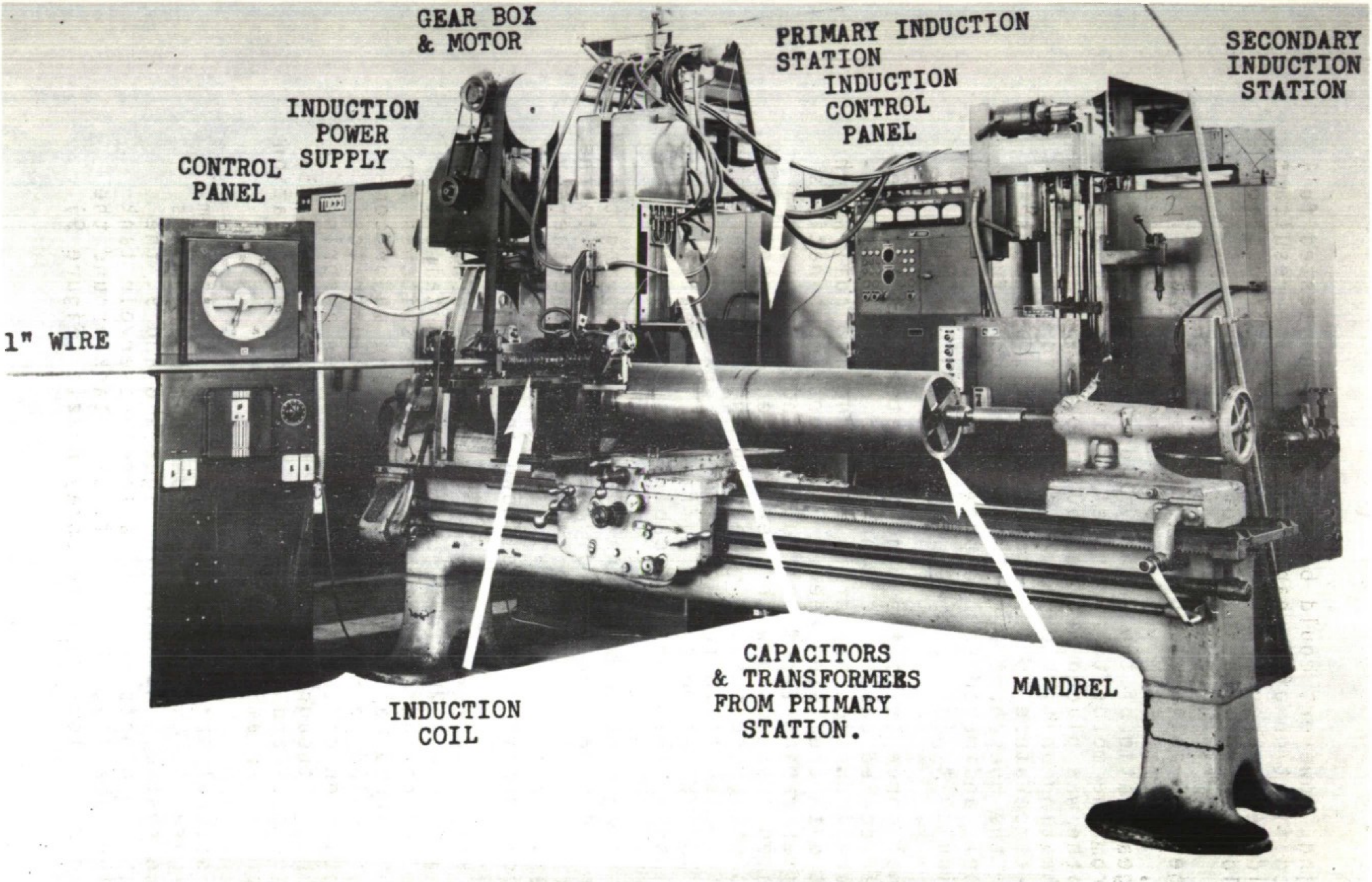


FIGURE 4 Hot Wound Spring with no Quench Modifications.
The 1 Inch Wire Extending to the Left, The Induction Coil,
Through which it Passes, The Transformer, and the
Capacitors All Move with the Lathe Feed to Form
the Wire in a Helix on to the Cylindrical Mandrel of the Lathe.
(Compare with Figure 6)
(11-199-0893/AMC-72)

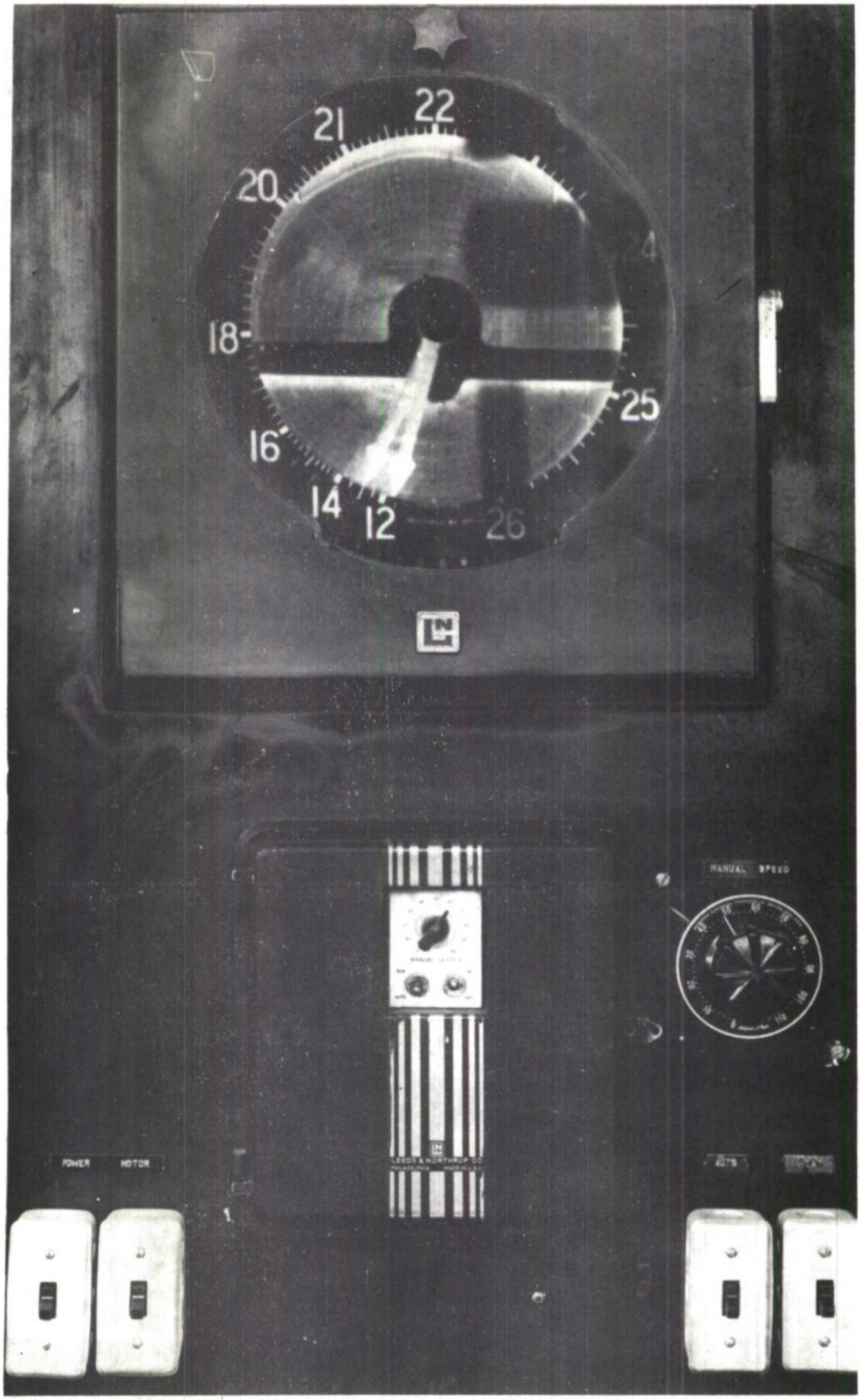


FIGURE 5 Control Panel Shown at Left in Figure 4. (11-199-899/AMC-72)

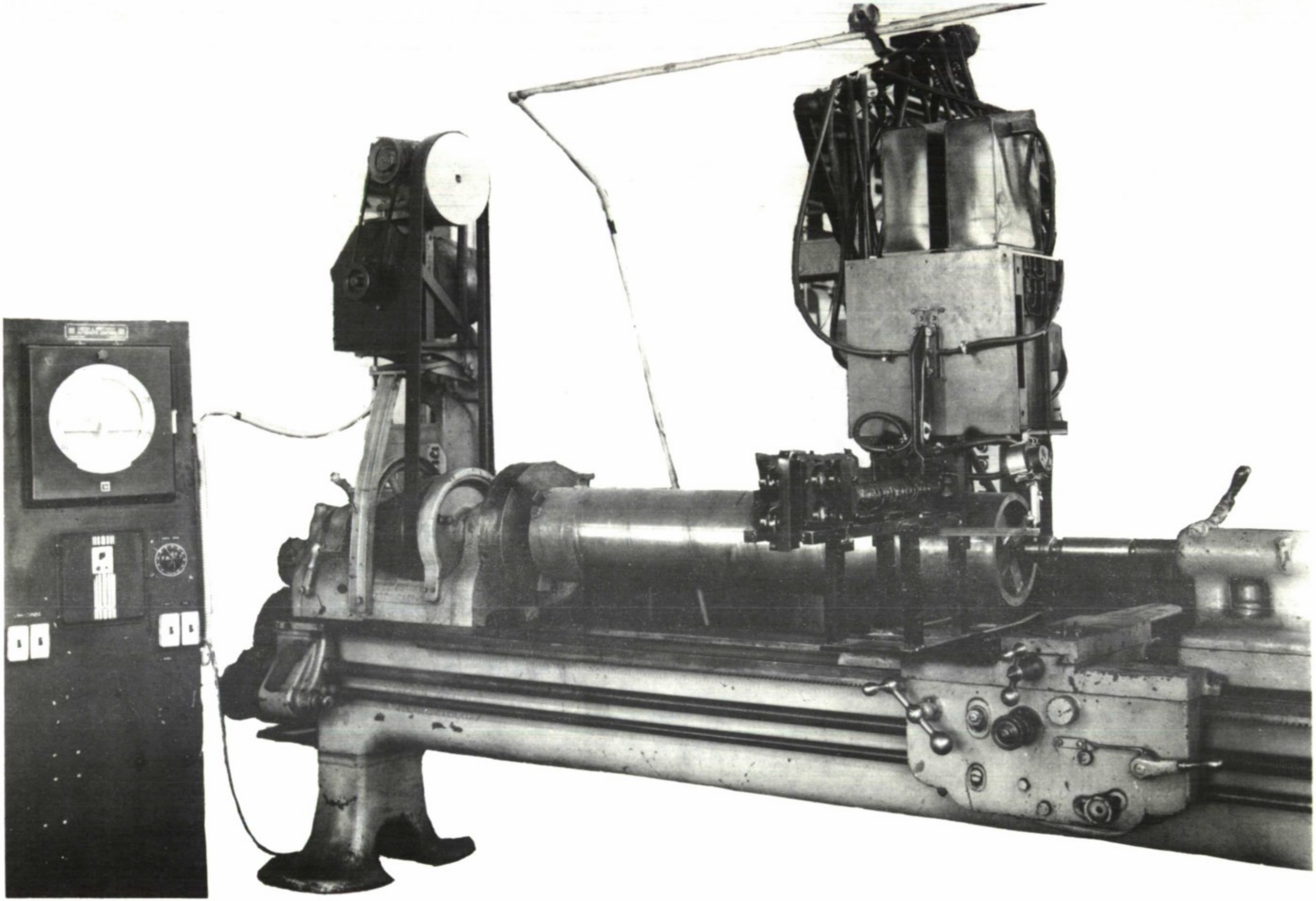


FIGURE 6 Hot Wound Spring Unit. Similar to Figure 1 with the 1 Inch Wire Removed and the Lathe Feed at Opposite End of the Mandrel.

(11-199-898/AMC-72)

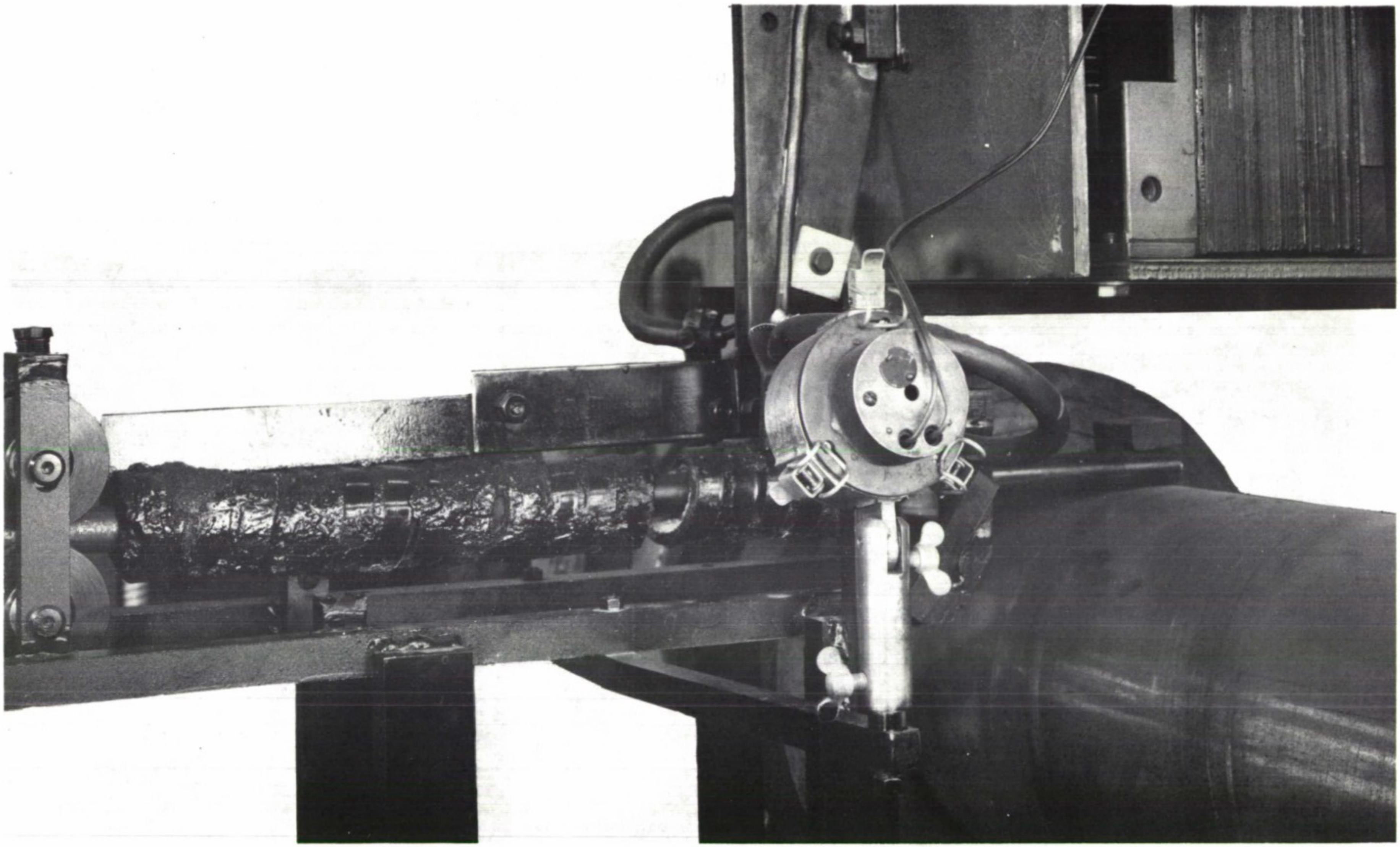


FIGURE 7 Final Induction Coil, 20" Long X 1-3/4" I.D.
Tubing was 3/4" X 3/8".
The Circular Radiation Pyrometer is Aimed at the Opening in the Coil.
(11-199-897/AMC-72)

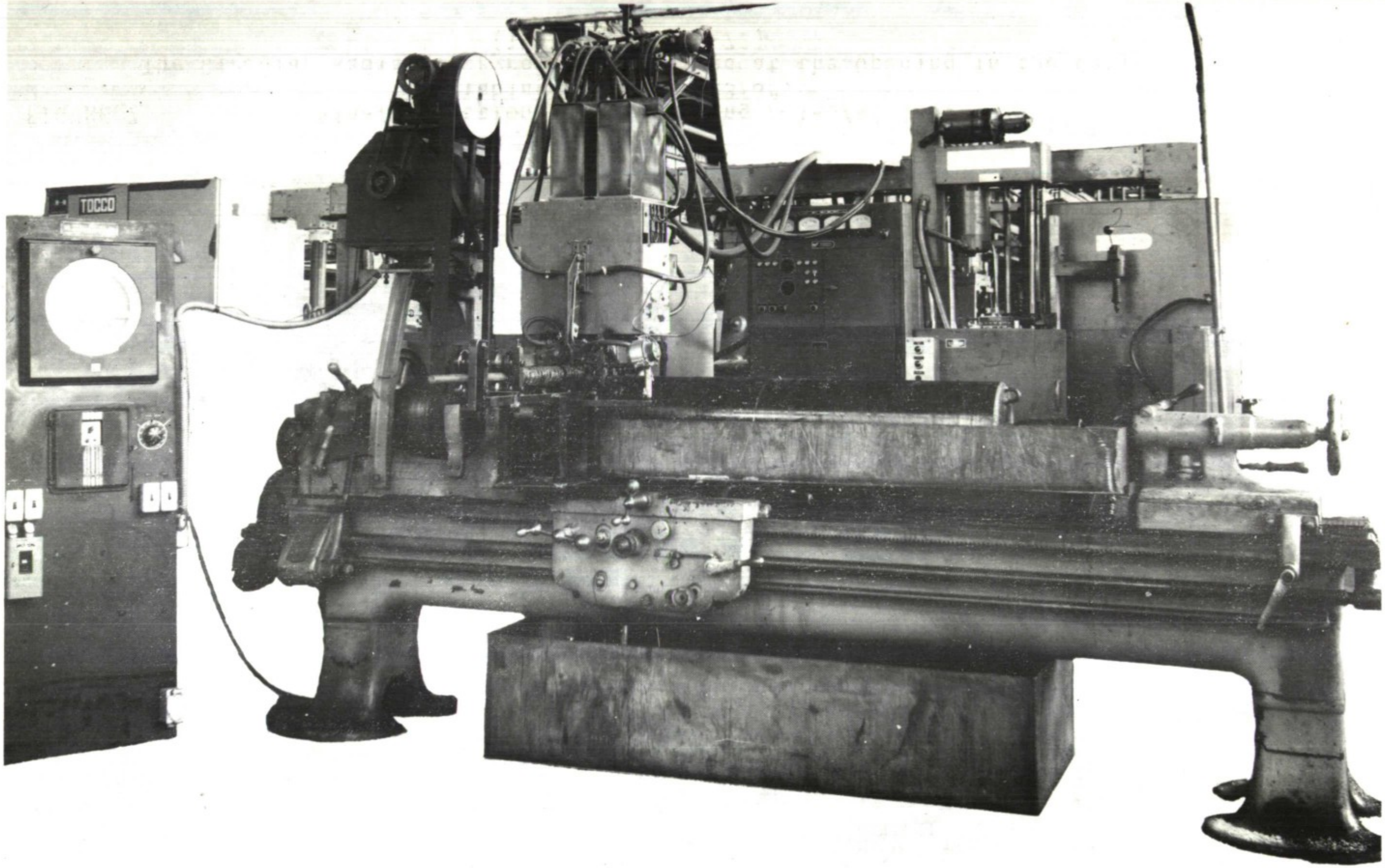


FIGURE 8 Hot Wound Spring Unit with Quench Modifications.
(Compare with Figure 1)
(11-199-1264/AMC-72)

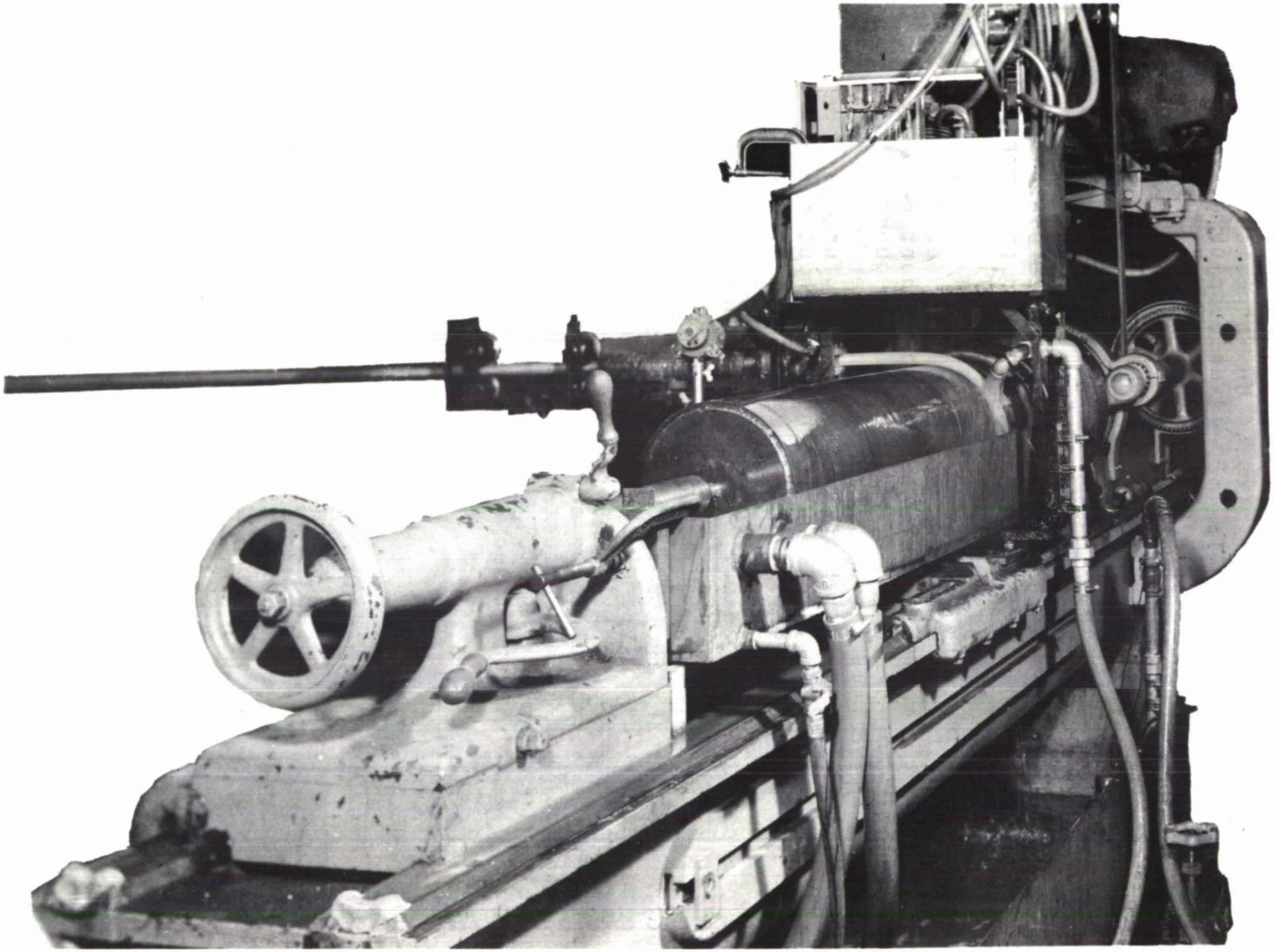


FIGURE 9 Back Side of Winding Unit
Showing a Spring Being Wound and Quenched.
(11-199-1271/AMC-72)

A circulation pump was located in the reservoir tank, but it is not well illustrated in Figure 9. Since most quench oils present a fire hazard when sprayed on hot metal, a substitute coolant was necessary. An inverse soluble, nonflammable liquid organic polymer, oxyalkylene, in a water base was selected. (The brand was Tenaxol Ucon Quenchant A.) The polymer precipitates from solution above 165°F and coats or partially insulates the part from the water. The water is normally a very drastic quench and, by varying the percentage of polymer in the bath, a violent water quench to a slow oil quench can be achieved. Little experimental work was expended researching the variables of the organic polymer or similar substitutes since it was not germane to the feasibility study, although a coolant other than oil was certainly necessary to the quenching technique used. Further quenchant research was also not persued because the polymer quenchant is in use commercially, in fact, one heat treater has changed to the polymer exclusively on an entire furnace line and eliminated use of oil quenching throughout his plant, (Reference 2). Because the polymer coats the hot metal, a violent agitation of quenchant is not recommended by the quenchant manufacturer, hence the low pressure spray nozzle mentioned earlier and a small circulating bath tank for the cooling spring to rotate in. Other advantages of the polymer quenchant include: (1) No degreasing - most of the polymer is dissolved back into the quenchant as the spring cools, (2) No oil smoke during tempering from deletion of the normal cleaning or degreasing operation, and (3) The polymer is nonsurfactant (not an oxygen "getter") and can be disposed of in sewer systems without creating a pollution problem such as oils do.

<u>Winding Springs</u>

Once the system was developed, little problem was encountered winding the three spring materials. Winding temperatures from 1500°F to 1900°F were used. The maraging steel was more resistant to bending and higher winding temperatures were necessary to prevent bending or breakage of the fixture that held the induction coil. Only one small center bolt directly below the mandrel held the fixture to the lathe feed. With a stronger fixture the 1500°F temperature, the solution heat treatment temperature for marage material, could have been used.

All springs were wound by activation of the induction coil and initial hand-feeding of the end of the 1-inch wire through this heating coil to the position shown in Figure 7.

The quench, if it were to be used, was turned on. The lathe motor was activated, and the automatic lathe speed and heat control (controlled through the radiation pyrometer signal) was turned on. The "dog" shown at the top of the mandrel would then grip the end of the wire as the lathe turned.

For 1-1/4 to 1-1/2 mandrel revolutions the lathe feed was left in neutral and was moved slightly by hand to form the closed end-coil and to lead into the 8-1/2-inch pitch helical configuration of the main spring body. The coil fixture was also rotated about its center bolt to give the 18°41' angle required for the pitch. The fixture is shown in this rotated position in Figure 10, although the picture angle does not make the rotation obvious. This procedure was reversed at the end of the spring to close the last coil.

The entire system operated automatically in a closed loop mode, as shown in Figure 10, for the winding of the main body of the spring. If the temperature of the wire inside the coil (as monitored by the pyrometer shown in Figure 7) deviated approximately ± 10°F from the preset temperature, the induction coil was automatically turned on or off, as required, to return to the set temperature. Furthermore, the output signal from the radiation pyrometer was fed to a servomotor which changed the speed of the lathe (Figure 11). Although no attempt was made to perfect these controls, an external temperature monitoring pyrometer showed that in general ± 20°F to 40°F from the set temperature was maintained. Generally, eight minutes were required to wind a spring. Although each spring was not timed precisely, the lowest temperatures allowed faster winding, by 1-2 minutes, and the highest temperatures a correspondingly longer time. The speed control ranged from mandrel speeds of zero to 6-1/4 rpm maximum; therefore, at top speed approximate 4-1/4 minutes would have been required to wind a spring.

As subsequent discussion and data show, the parameters of diameter and hardness were not maintained as would be required in production facilities. Both of these parameter variations were caused by temperature fluxuations along the length of the bar, especially the first coil where the bar was hand-fed through the induction coil and the temperature estimated visually by color change. A variable speed-driven roller on the feed side of the coil could eliminate this problem.

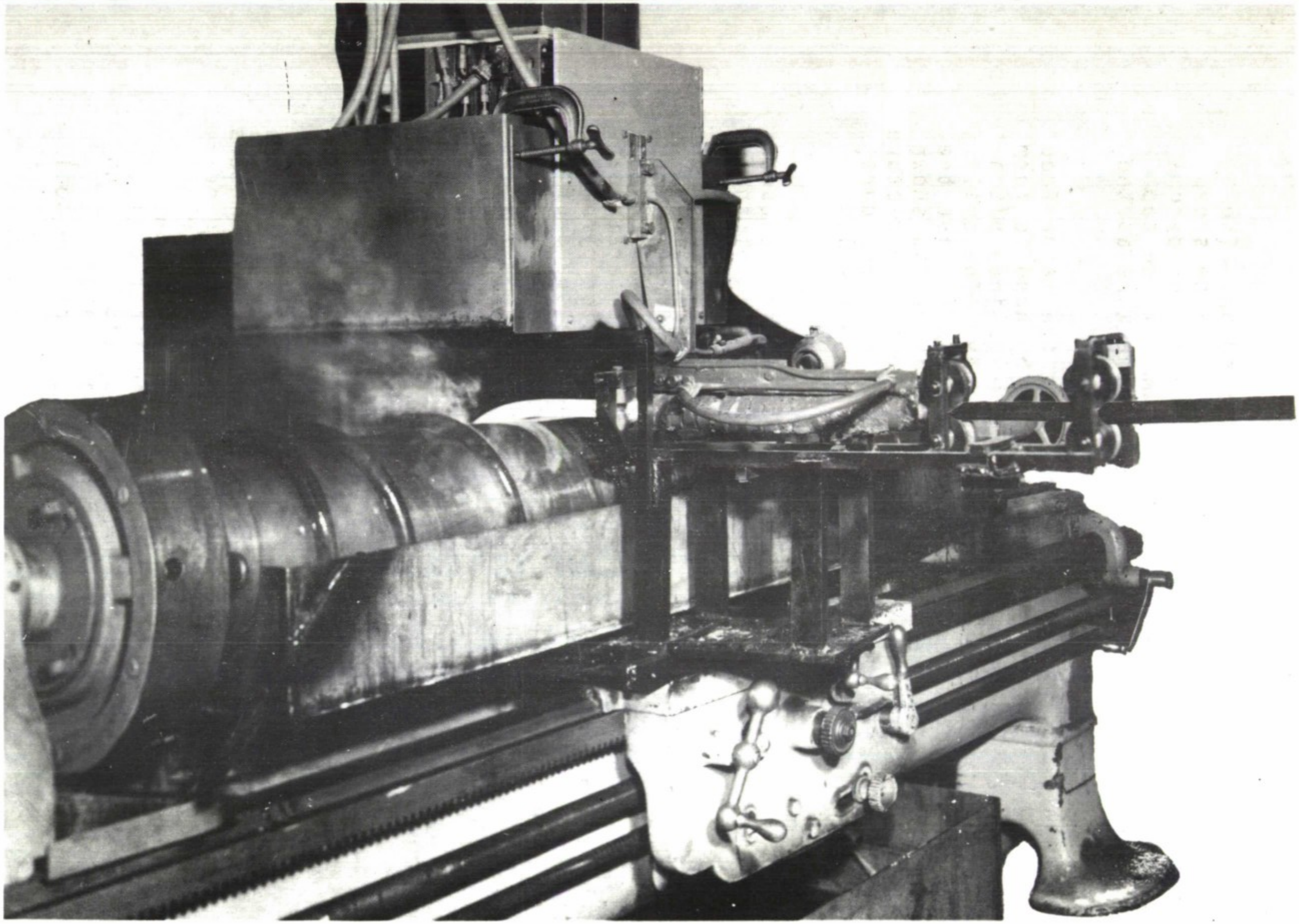


FIGURE 10 Hot Wound Spring System in Operation. Quench Tanks Installed and in Use. (11-199-1269/AMC-72)

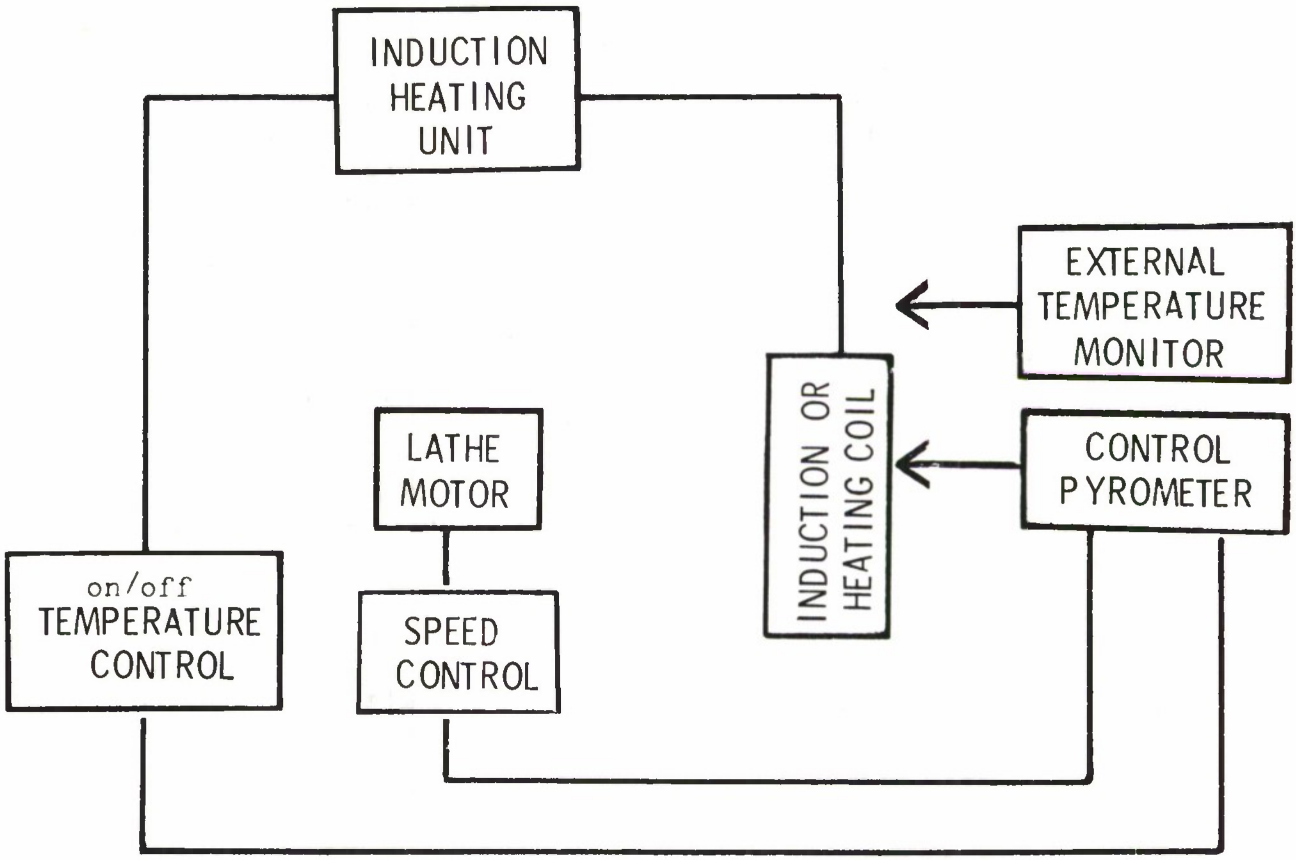


FIGURE 11 Schematic of the Controls Used in the Hot Wound Spring Unit. (11-199-1678/AMC-72)

The winding process was reduced considerably by winding at the austenitizing temperatures and quenching on the mandrel, as Table I illustrates. Many manufacturers eliminate the step of heating to the proper austenitizing temperature by removing the still hot spring from the winding mandrel and oil quenching the spring. This practice is not allowed by the manufacturing specification MIL-S-13572 for Class A Springs. One benefit of not allowing a quench from normal hot wind operations is a reduction of grain size. Manufacturers who quench from winding must hot-wind at high temperatures - causing grain growth - because of at least two factors. First, the spring while being transported from a furnace to the coiling equipment, while being coiled, while being removed from the coiling mandrel, and while being transported to the quench is losing heat; therefore, the wind temperature must be high enough to allow the spring to be above the critical quenching temperature (A_{r_3}) when it reaches the quench tank. Second, the hotter the straight bar or wire being used, the lower the power required to coil the bar and the less rigid and costly the winding equipment needs to be. The undesirable features of both factors were eliminated in the experimental hot-winding system by heating and quenching any given coil within approximately one minute.

The hot-winding practice required by MIL-S-13572 for Class A Springs also has disadvantages. The second heating for austenitizing causes more scaling and decarburization since manufacturers do not have controlled carbon potential atmospheres in their hot-winding or their heat-treating furnaces. Requiring controlled atmospheres would probably mean manufacturers would have to purchase new furnaces in both areas plus atmosphere generating equipment and controls, all of which would be prohibitively expensive. A further disadvantage of the military specification practice is size control. Further heating and cooling tends to distort the spring configuration, especially the long open-coil type of spring used in the M140 Gun Mount. These disadvantages are minimized in normal manufacturing by holding furnace times to a minimum and, in some cases, putting the springs on fixtures before heat treating. The decarburization is essentially zero in the experimental system and, with good heat-control, distortion is not a problem; indeed, the mandrel acts as a heat-treat fixture. The experimental system can, therefore, comply with the intent of the military requirements while minimizing or eliminating the disadvantages of those requirements. The system can be adopted to in-use conventional-systems by adding an induction unit and quench tank.

TABLE I

COMPARISON OF MANUFACTURING METHODS

Conventional Process			Proposed Process		
	Operation	Estimated Time, Minutes		Operation	Estimated Time, Minutes
1.	Heat bar	30-60	1.	Heat, Coil, Quench	10
2.	Coil Spring	1-2	2.	Temper	60
3.	Cool	30			
4.	Austenitize	60			
5.	Quench	10			
6.	Degrease	10			
7.	Temper	60			
	Total	201-233		Total	70

Cost of equipment and power, of course, must be considered. One spring manufacturer in private correspondence estimated $90,000 as the cost of a new furnace without atmosphere control just to be used to heat bars approximately 27 feet long for hot winding. The cost of a heat-treat furnace would depend at great deal upon size which would depend upon the total requirement of a given manufacturer; it would probably be considerably less than the large bar furnace. The experimental system requires one induction unit that, dependent upon size, would cost approximately $50,000. Both the current manufacturing system and the experimental system require comparable winding equipment. The latter would require the quench modification but this would be no costlier than the oil-quench systems needed in current manufacturing processes.

The power requirements, of course, will also vary from manufacturer to manufacturer depending a great deal upon total volume of an operation and discounts on natural gas or electricity. The power cost to heat the bar in the experimental system was $0.30 based on the use of 60% of the rated 150 KW induction unit and on an estimated 85% efficiency of the generator that supplied current to the induction station transformer and capacitor bank (1.7¢ per KWH). This cost will generally be higher than gas heating; one estimate for gas was $0.23 per bar based on $0.003 per pound of material ($0.63 per 1000 ft^3 of gas and 27 ft. bars). The cost of heating the coiled spring for quenching, to comply with the military requirements, would make the power costs comparable; hence, the two systems would cost nearly the same to heat a bar but the proposed induction heating system would cost approximately half as much to procure as conventional heating systems and the proposed system can eliminate or combine several operation steps.

All 23 pieces of 1-inch wire used in the project were coded as shown in Table II. From these five springs of 5160-H material, two of 9262-H and two of Grade 250 maraging were made for a total of nine acceptable springs. Spring V was 10 pounds (1/3%) below the 2800 pound minimum, but this alone is not considered significant. Two springs were used in preliminary winding to test the system; two springs that were air cooled from winding were later heat treated improperly; five springs were used in quench tests concomitant with winding; one spring was not completed because of a power failure in the induction unit; two springs slipped from the mandrel dog in the process of winding, and two pieces of 5160-H stock were not used. Many of the

TABLE II

GENERAL DATA

Spring or Wire Code	Alloy	Winding Temp, °F	Quench	Load at 22½ In. (Lbs)	Remarks
A	5160-H	1550	Air	2660	Low load caused by improper heat treatment
B	5160-H	1575	Air	----	Improper heat treatment
C	5160-H	1700	Air	2990	
D	5160-H	1800	Air	2960	
E	5160-H	1500	18% Polymer	2980	Open coil
F	5160-H	1500	18% Polymer	3020	
G	5160-H	1620	---	----	Used in early quench test
H	5160-H	1700	---	----	Used in early quench test
I	5160-H	1800	---	----	Used in early quench test
J	5160-H	1600	18% Polymer	----	Induction unit failed while winding
K	5160-H	1500	18% Polymer	3060	
L	5160-H	1800	18% Polymer	----	Used in quench test
M	5160-H	----	---	----	Not used - in Forge Shop
N	5160-H	----	---	----	Not used - in Forge Shop
O	5160-H	----	Air	----	Used in early test wind
P	9262-H	----	Air	----	Used in early test wind
Q	9262-H	1575	18% Polymer	----	Slipped from dog on mandrel
R	9262-H	1875	22% Polymer	2830	
S	9262-H	1540	22% Polymer	2000	Quenched too slow
T	9262-H	1500	18% Polymer	3040	
U	250 Marage	----	---	----	Slipped from dog on mandrel
V	250 Marage	1900	18% Polymer	2790	Considered acceptable
W	250 Marage	1900	18% Polymer	2880	

springs or partial springs, which failed load tests, yielded considerable laboratory test data, e.g., hardness, microstructure, and configuration data. The results from these springs are included in the following data and discussion.

Diameter Variance

The spring diameter is controlled principally by the diameter of the mandrel upon which the hot bar is wound. The air-quenched springs (A-D, Table III) were hot-wound on a straight 11-1/2-inch O.D. mandrel. Since the springs had to be hammered off the mandrel and, because of verbel manufacturer's reports of shrinkage on to the mandrel, the mandrel was tapered from 11-1/2 inches for the first coil to 11-1/4 inches for the last coil while quench modifications were being made. No attempt was made to make several mandrels of various shapes and sizes to determine which size and configuration would best meet the drawing requirements; most manufacturers will have much experience already. All of the springs quenched on the mandrel were easily removed from the mandrel.

The coil diameters for four different winding temperatures are given in Table III. The average diameter of the hotter springs was greater, i.e., more springback occurred because of the lower elastic modulus of the hotter bar (yield strength, true stress-strain, and plastic strain also influence springback p. 561, Reference 1). No statistical differences, however, could be inferred either from coil to coil within a spring or from spring to spring.

Snedecor's "F" test for variance ratio was applied to each spring (1) by placing the eight diameters into two or four groups and comparing groups, (2) by using all the diameter values from one spring as a group and comparing one spring to another in groups of two, or comparing the springs in groups of four. The "F" test is a test for internal consistency of a single string of measurements where the variance between sample groups is compared with the variance within sample groups. The calculated "F" values were compared with standard tabular values that would be exceeded by chance alone 5% of the time. In no case did the calculated value exceed the tabular value, hence, no statistical difference could be drawn. See Appendix B for the Focal language computer program used to calculate "F" values and a table of the results.

TABLE III

WIND TEMPERATURE EFFECT ON DIAMETER. 5160-H AS WOUND ON STRAIGHT MANDREL AND AIR COOLED

	Diameter in Inches				
Spring	A	B	C	D	
Wind Temp, °F	1550	1575	1700	1800	Coil
	13.594	13.594	13.562	13.562	1
	13.500	13.500	13.531	13.594	2
	13.594	13.500	13.562	13.531	3
	13.594	13.500	13.562	13.937	4
	13.500	13.500	13.500	13.625	5
	13.468	13.500	13.500	13.594	6
	13.406	13.531	13.937	13.500	7
	13.500	13.656	13.594	13.500	8
Average	13.520	13.535	13.594	13.605	

Similarly, the Student's "t" test was applied to compare the diameter values of one spring to the values of each of the other springs. The "t" test compares the difference between averages. Again, a 5% probability level was chosen, and, again, the calculated "t" values were always less than the standard values, hence, no statistical difference could be inferred. The Focal language computer program and the "t" values are given in Appendix C.

The "as wound" diameter of four springs that were quenched on the mandrel are given in Table IV. Compared with the air-quenched springs of the same material (Table III), the average diameter at a given temperature is larger. The "F" values for these springs are given in the first four groups tabulated in Appendix D. No difference was found when the diameter values for a spring were compared in groups of two or in groups of four. The latter compared the first four coils with the last four coils to measure the effect of the tapered mandrel on the diameter. The within sample variance was too great to detect a between sample (first half to second half) variation.

The "F" test did not reveal a difference from spring to spring when compared one to one or all four at one time.

The "t" values in which averages are compared are also given in Appendix D. In only one case was a significant difference noted when the diameter values of Table IV were compared in groups of two. When the diameter values of Table IV for quenched springs were compared with air cooled values in Table III, a more significant difference appeared as is shown by the calculated "t" values exceeding the standard values, i.e., the quenched (18% polymer in H_2O) diameters are larger even though the mandrel was tappered 1/4 inch smaller at one end.

Few measurements were available to determine the changes one might expect during heat treatment and presetting. However, the data for Springs D and F (Table V) indicate slightly larger diameters following the presetting (cycling from free height to solid, Figures 1-3). The statistical "F" test results revealed no significant difference in the internal consistency of data for Spring D except for the tempered condition when the diameters were compared in groups of twos (F calculated = 11.17, Std. = 6.59). Similarly the "t" test found no statistical difference between the average diameters of the different conditions given in Table V for Spring D. The data for Spring F, however, indicated a significant difference in diameters from end to end in the preset condition, although, no difference was found in the as wound-quenched

TABLE IV

WIND TEMPERATURE EFFECT ON DIAMETER. 5160-H AS WOUND ON A TAPERED MANDREL AND QUENCHED WITH 18% POLYMER IN H_2O

	Diameter in Inches				
Spring	F	G	H	I	
Wind Temp, °F	1500	1620	1700	1800	Coil
	13.630	13.637	13.754	13.637	1
	13.603	13.656	13.658	13.605	2
	13.592	13.616	13.642	13.600	3
	13.559	13.600	13.624	13.590	4
	13.600	13.552	13.575	13.536	5
	13.586	13.604	13.648	13.596	6
	13.565	13.615	13.645	13.638	7
	13.548	13.642	13.688	13.677	8
Average	13.585	13.615	13.654	13.610	

TABLE V

DIAMETER CHANGES DURING PROCESSING

Preceeding Operation	Diameter in Inches: Spring D, Wound at 1800°F: Wound	Oil Quench From 1525°F	Temper 725°F	Preset	Spring F, Wound at 1500°F: Wound-Quench (18%)	Preset	Coil
	13.562	13.563	13.594	13.615	13.630	13.735	1
	13.594	13.594	13.707	13.655	13.603	13.710	2
	13.531	13.532	13.532	13.655	13.592	13.740	3
	13.937	13.532	13.532	13.620	13.559	13.730	4
	13.625	13.470	13.470	13.610	13.600	13.658	5
	13.594	13.470	13.470	13.620	13.586	13.670	6
	13.500	13.470	13.844	13.650	13.565	13.630	7
	13.500	13.720	13.720	13.660	13.548	13.675	8
Average	13.605	13.544	13.609	13.636	13.585	13.694	
"F" factor	0.91	0.84	11.17	3.33	6.33	10.22	Calculated
4 Groups	9.12	9.12	6.59	6.59	6.59	6.59	Std @5%
"F" factor	1.03	0.24	0.15	1.64	2.12	33.0	Calculated
2 Groups	234	234	234	234	234	5.99	Std @5%
"t" factor	Wound-Preset		0.597		5.980		Calculated
			2.145		2.145		Std @5%

condition. The "t" test cannot be considered completely valid when applied to the internally not consistent preset data for Spring F, but the test results indicated a significant difference between the two sets of data given for Spring F. From these limited number of statistical tests one can tentatively conclude that quenching on the mandrel subsequently produces a tapered spring significantly larger in diameter than it was as wound, whereas air cooling and subsequent heat treatment is inconclusive. Close examination of the data for Spring D shows a wide scatter in diameters; hence, the inclusive results.

Height Variance

Since the end coils were not made mechanically, much human error exists in the absolute height values from spring to spring. The percentage of change, however, is important in spring manufacture. As Table VI shows, the percentage of loss is generally less for maraging steel than for the low alloy steels. The heights to which the springs were wound were estimated from Equation (10) of Appendix E. The springs lost approximately 1 inch in height when changed from a horizontal position to the vertical position in which load measurements and preset data were collected. Note that the springs were not tapered or ground on the ends (Figures 1-3) as the drawing in Appendix I illustrates. Therefore, the solid heights of the test springs tended to be larger and influenced the estimated wind heights.

Microstructure Variance

An increase in winding temperature affects the grain size most notably with lesser effect upon hardness, load, or spring size. Subsequent austenitization heat-treatments can refine the grain size; hence, the effect is best seen in the springs listed in Table VII. The higher temperatures produced larger grain size in all three materials. Generally, best mechanical performance is obtained with fine-grained materials. For this reason, as discussed earlier, the spring manufacturing specification MIL-S-13572 (Para 3.1.2) requires Class A Springs to be cooled below the transformation temperature before final heat treatment. Because most springs are hot-wound near the 1800°F-1900°F temperature range, the requirement to cool before heat treatment (usually 1500°F-1600°F) is reasonable. Since cooling and proper heat treating are costly operations, most manufacturers wrongly call the process "double heat treatment."

TABLE VI

FREE HEIGHT MEASUREMENTS

Spring	Height, Inches		Change in Height		During 5 Cycles***		
	Wound*	Preset**	Total Inches	%	Actual Inches	Actual Allowed	Cycle Number
5160-H							
C	52.437	46.500	5.937	11.3	Zero	0.0942	8-13
D	51.562	45.500	6.062	11.8	0.0625	0.0911	9-14
E	52.750	47.625	5.125	9.7	Zero	0.0952	8-13
F	53.500	47.500	6.000	11.2	0.0625	0.0951	6-11
K	---	47.000	--	--	Zero	0.094	10-15
9262-H							
R	52.500	46.062	6.438	12.3	0.0625	0.0923	5-10
T	52.062	46.934	5.128	9.8	Zero	0.0939	12-18
250 Marage							
V	51.000	47.438	3.562	7.0	0.0625	0.0931	4-9
W	49.500	46.125	3.375	6.8	Zero	0.0923	7-12

*Measured horizontally after removed from the mandrel.

**Measured vertically after preset.

***Measured vertically before and after preset.

TABLE VII

GRAIN SIZE

Material	Spring	Winding Temperature, °F	ASTM* Grain Size
5160-H	J	1600	8
	K	1500	7-8
	L	1800	4-6
	Q	1575	7-8
9262-H	R	1875	4-6
	S	1540	8
	T	1500	8
250 Marage	V	1900	5-6
	W	1900	6

* $n = 2^{N-1}$, where n = number of grains per square inch at 100X magnification and N = ASTM grain size. Therefore, larger grain size (fewer per square inch) is indicated by smaller numbers.

The proper heat treat also increases coil distortion as does any heating and quenching operation. The system, described in this report, eliminated the necessity for reheating by demonstrating that winding at the proper heat-treat temperatures is feasible and, further, that the system can help reduce distortion by quenching on a fixture, viz., the winding mandrel.

The drawing (Appendix A) requires 100% martensite with no bainite or ferrite in the microstructure of the low-alloy steels. Load parameters can be met with less than 100% martensite; however, similar to fine-grain size, the all-martensitic structure is generally considered superior in performance than mixed microstructures. Completely martensitic structures are readily obtained in the 9262-H material with an oil quench. The reverse soluble polymer (22%) in water produced all martensite in 9262-H quenches from 1875°F (Spring R) but not in 9262-H quenched from 1540°F (Spring S). At an 18% level in water a near 100% martensite structure was produced from 1575°F (Spring Q). Therefore, at 10-15% concentrations, the quench would satisfactorily duplicate oil quenching from 1500°F. Reference 2 which was published after completion of the work in this reports suggests 10-13%.

The 5160-H steel produced similar results with the 15% polymer and would require lower polymer concentrations for quenching from approximately 1500°F. At higher metal temperatures of 1600°F-1800°F, the 5160-H material quench cracked, but responded satisfactorily when air cooled from higher temperatures and then properly heat treated.

The maraging material will produce a 100% martensite structure with a slow air cool, hence, quenching to form martensite is not a problem. Undesirable precipitates can form, however, if the maraging steel is cooled slowly by air, especially in the higher temperature ranges of 1600°F-1900°F. A quench was therefore used.

Quenching on the mandrel followed by tempering produces clean surfaces. Little scale was formed and only rare traces of partial decarburization were detected on any of the samples from the three materials. Normally the 9262-H material has 0.005 to 0.008 inch decarburization, 0.002 inch of which has total loss of carbon. This improvement in normal spring applications can increase life tremendously. Experience has shown that the 5160-H steel is less prone to decarburization, but 0.002 inch is not uncommon. Chemistry changes in the low-carbon marage

material are also usually low. But, here too, keeping the change to a minimum is a beneficial step to spring manufacturing.

Hardness Variance

All hardness measurements were made on transverse disks about 1/4-inch thick cut from selected coils. The measurements were taken along a line parallel to the diameter as shown in Figure 12. A considerable hardness range was usually found from coil to coil and sometimes even within a coil (Tables VIII and IX). This was to be expected since, as mentioned in the discussion of winding springs, no attempt was made to perfect temperature controls; thermal variations existed; hence, different quench rates and hardness readings were obtained. Induction heating units with ± 10°F or less variation, i.e., comparable to production furnace accuracy, are available.

Because of the wide range in hardness values, no group of the 9262-H steel hardness readings passed the statistical "F" test as being consistant, e.g., Spring T in Table IX. This indicates that a process variable, heat, was influencing the hardness beyond normal statistical variation. Similar "F" test results were obtained from Springs A (Table VIII) and J of the 5160-H steel, and springs V and W of the maraging steel; the remaining hardness values were not subjected to statistical analysis.

CONCLUSIONS

1. Helical spring manufacture is feasible with induction heating methods, at least, in stock up to 1-3/32 inches in diameter.

2. The springs can be coiled at austenite temperatures normally used in heat treatment.

3. The coils can be quenched on the mandrel as subsequent coils are being heated and wound.

4. The as-coiled springs quenched on the mandrel had larger diameters than springs that were air-cooled.

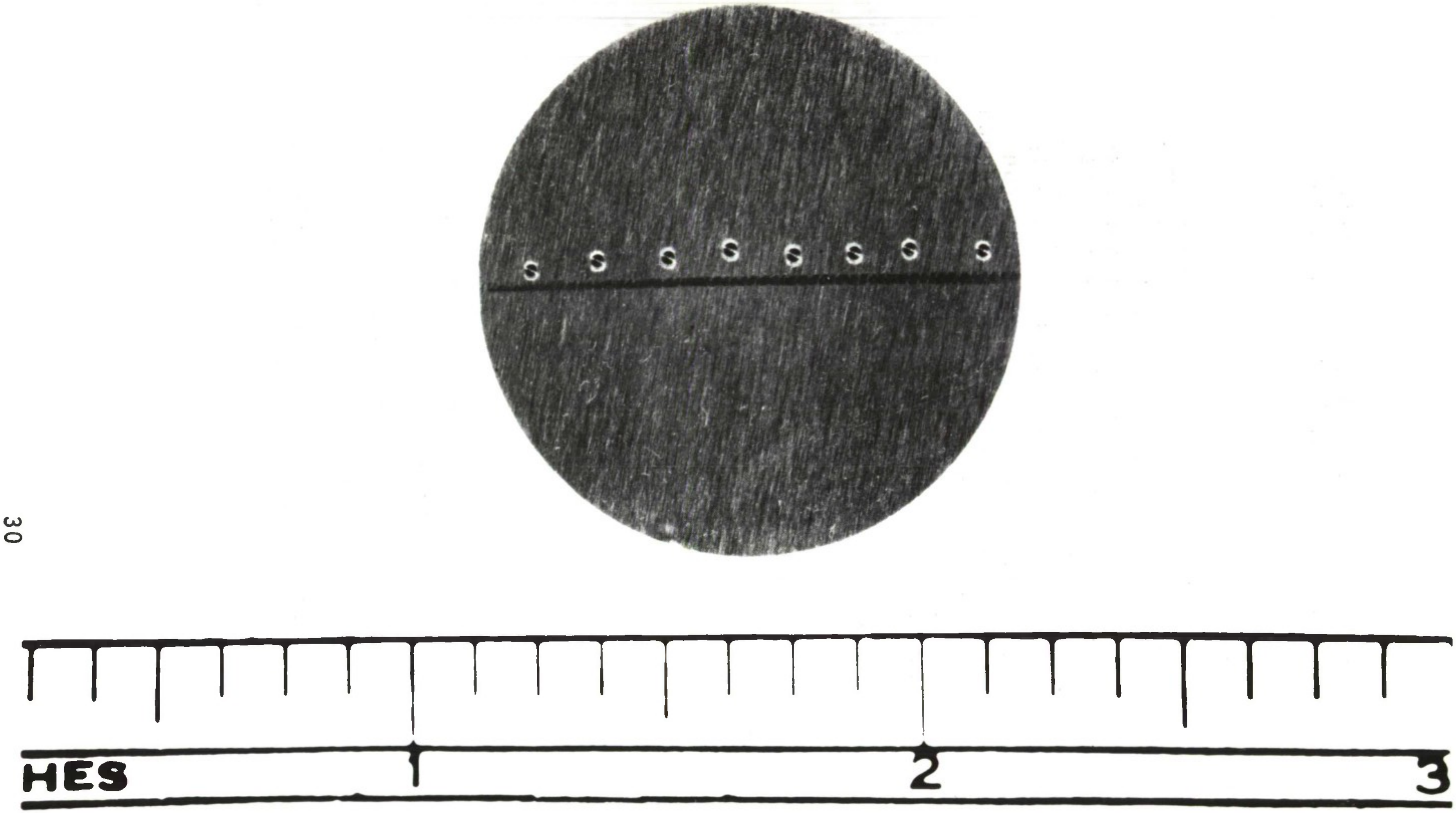


FIGURE 12 Transverse Disc Showing Hardness Survey Method.
(11-199-1341/AMC-72)

TABLE VIII

SUMMARY OF R_C HARDNESS READINGS

Spring	Quenched Average	Quenched Range	Tempered or Aged Average	Tempered or Aged Range	Major Parameters: Material	Major Parameters: Heat Treat
A	--	--	50.2	4.5	5160-H	Air cooled, austen-
C	--	--	50.1	3.0	5160-H	itized, quenched and tempered
J	62.7	10.5	49.6	4.0	5160-H	Mandrel
K	--	--	49.3	6.0	5160-H	quenched and
L	63.8	5.5	50.5	3.5	5160-H	tempered
Q	58.1	16.5	48.3	8.5	9262-H	Mandrel
R	--	--	47.3	8.0	9262-H	quenched and
S	--	--	42.3	16.0	9262-H	tempered
T	--	--	50.3	7.5	9262-H	
V	--	--	48.1	4.0	250 Marage	Quenched and aged
W	--	--	48	5.0	250 Marage	Quenched, Sol. H.T., and aged

TABLE IX

EXAMPLE OF ROCKWELL C HARDNESS SURVEYS

Spring A, 5160-H

Coil 1	2	3	4	5	6	7	8
50.0	50.0	49.5	50.0	50.0	50.5	49.0	51.0
50.5	51.0	50.5	50.5	50.5	50.0	50.0	51.0
50.5	50.5	50.5	50.5	51.0	50.0	50.0	51.0
50.0	50.5	50.5	51.0	51.0	50.0	50.5	51.0
50.5	50.5	50.0	51.0	50.5	50.0	50.5	50.5
50.0	50.5	50.0	50.5	50.5	49.5	50.0	50.0
50.0	50.5	49.5	50.5	50.0	49.0	50.0	50.0
49.5	50.0	49.5	50.5	50.0	48.5	49.5	50.0
50.0	50.0	50.0	50.5	50.0	49.0	49.5	50.0
50.0	50.0	50.0	50.0	50.0	49.0	49.5	50.0
50.5	50.0	50.5	50.5	50.5	49.0	50.0	50.5
51.0	49.5	50.5	51.0	51.0	49.5	50.0	50.5
50.5	49.0	51.0	51.0	51.0	50.0	50.5	51.0
50.5	48.0	51.0	51.0	51.0	49.5	51.0	51.0
50.5	46.5	51.0	50.5	51.0	49.5	51.0	51.0
	47.0		50.5			50.5	

Calculated "F" factor = 5.87

Standard "F" factor (@5%) = 3.26

Spring T, 9262-H

Coil 1	2	3	4	5	6	7	8
49.5	46.5	50.0	50.0	48.0	48.0	48.0	49.5
49.0	48.5	50.5	51.0	48.5	48.0	49.0	50.5
49.0	48.5	50.5	51.5	49.0	49.0	49.5	50.5
50.0	48.5	51.0	51.0	49.0	50.0	49.5	50.0
51.0	48.5	51.0	51.5	49.5	49.5	50.0	50.5
52.0	50.0	52.0	52.0	50.5	52.0	50.5	51.0
52.0	50.0	52.5	53.0	51.0	52.0	51.0	52.5
51.0	51.0	53.5	53.5	52.0	51.0	52.0	53.0
50.0	51.5	53.0	53.5	51.0	50.5	52.0	52.5
49.5	51.5	52.0	53.0	54.0	49.5	52.0	51.5
49.5	51.5	51.5	52.0	48.5	49.5	50.5	50.5
49.0	49.5	51.0	51.5	48.5	49.5	49.5	50.0
(50.0)	49.5	50.0	51.0	48.5	50.0	49.0	50.0
	50.5	50.5	51.0	48.0	49.5	48.5	50.0
	50.0	50.5	50.5	48.0	48.5	49.0	50.0
		50.0	50.0		48.5		49.0

Calculated "F" factor = 5.60

Standard "F" factor (@5%) = 3.28

Underlined values were not used to calculate "F".

RECOMMENDATIONS

1. A driven variable speed roller is needed to feed the first part of the bar stock through the induction coil and produce even heating of the stock from end to end.

2. A variable coiler (lathe) feed control, such as commercial manufacturers have, is highly desirable to reproduce uniformly any type of variable pitch springs.

3. Accurate closed-loop temperature control with two temperature sensors - one to monitor in the coil and one to monitor material just in front of the quench - is highly desirable to control point to point temperature fluctuations.

LITERATURE CITED

1. Dieter, George E., Mechanical Metallurgy, McGraw-Hill Book Company, Inc., New York, 1961.

2. Beck, A. J., Contributing Author, Heat Treating Magazine, February 1972, Vol. 4, No. 2, p. 18.

3. Hodgman, Charles D., et.al., Editor, Handbook of Chemistry and Physics, 40th Ed., Chemical Rubber Publishing Co., 1959.

4. Moroney, M. J., Facts From Figures, Penguin Books, London, 1956.

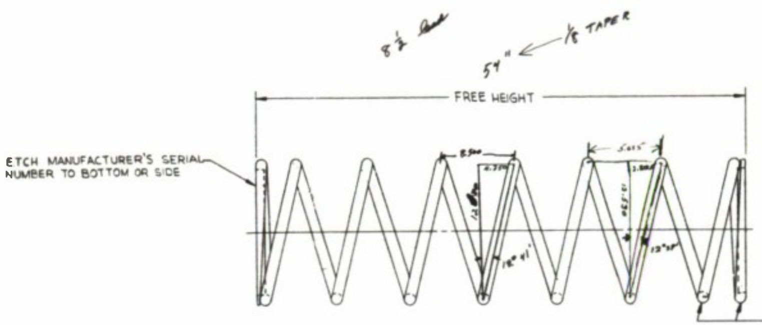
5. Ordnance Proof Manual 7-27.

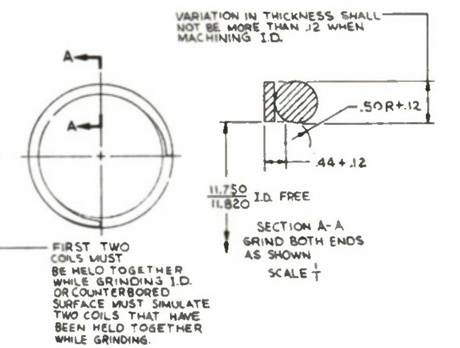
APPENDIX A

M140 GUN MOUNT SPRING DRAWING

			REVISIONS	DATE	APPROVED
		C		8-22-61	
		D	REDRAWN W/O CHANGE FROM		
			D SIZE	3-11-64	
		E	(E1) SPEC MIL-S-13572 WAS		
			SPEC 51-97-3 (E2) 9262 WAS		
			FS 9262 (E3) SPEC MIL-M-11472		
			WAS SPEC MIL-I-11472		
			(E4) "TOLERANCES" NOTE ADDED		
			(E5) "QUALITY ASSURANCE" NOTE ADDED	5-20-65	
		F	(1-10) SEE E.O. CC-C5807	2-17-67	
		G	(1-6) SEE E.O. CC-C8624	8-9-67	
		H	SEE E.O. CC-C9718	2-1-68	
		J	(1-6) SEE E.O. CC-C99A9	3-4-68	
		K	(1) SEE E.O. CC-D3640	9-24-68	
		L	REDRAWN W/C SEE E.O. MRD 1K002	7-3-69	
		M	SEE E.O. MRD 01002	1-7-70	

8½
54" ← ⅛ TAPER





SECTION A-A
GRIND BOTH ENDS AS SHOWN
SCALE 1/1

NOTE:

1. ALLOY STEEL, COMPOSITION 9262-H SPEC QQ-S-624 AND AMS 2301

2. MANUFACTURE IN STRICT ACCORDANCE WITH SPEC MIL-S-13572 TYPE I, GRADE A WITH THE FOLLOWING EXCEPTIONS AND ADDED ~~REQUIREMENTS~~

A. QUENCH AND TEMPER

B. MAXIMUM TOTAL PLUS PART A… DECARBURIZATION .010.

C. SHOT PEEN USING CAST STEEL SHOT

D. PHOSPHATE COAT AND SUPPLEMENTARY OIL TREATMENT VV-L-800

E. PROVIDE SIX INCH LONG SPECIMENS REPRESENTING ALL THERMAL TREATMENT (HEATING FOR COILING AND ALL OTHER TREATMENT CYCLES). ONE FROM EACH MILL HEAT AND TWO FROM EACH HEAT TREAT LOT. ONE SPECIMEN WITH THE HEAT TREATMENT LOT SHALL ACCOMPANY THE FIRST SPRING TREATED AND THE OTHER SPECIMEN, THE LAST SPRING TREATED. MICROSTRUCTURE SHALL BE 100% TEMPERED MARTENSITE. NO FREE FERRITE OR BAINITE PERMITTED. THE AVERAGE GRAIN SIZE SHALL BE ASTM MICROGRAIN SIZE NO. 7 OR FINER AT 100X AS SPECIFIED IN ASTM E112-63 COMPARISON PROCEDURE [illegible] 6, PLATE 1.

F. SQUARE AND GRIND ENDS. ENDS SHALL BE SQUARE WITH THE SPRING WITHIN 5 DEGREES.

G. IDENTIFY EACH SPRING BY ETCHING THE MANUFACTURER'S SERIAL NUMBER AND CODE.

H. ETCH [illegible] FOR APPROVAL IF MAGNETIC PARTICLE INSPECTION MET REQUIREMENTS.

J. BAR ENDS TO BE WEDGE SHAPED WITH A DEVELOPED LENGTH NOT LESS THAN 15 INCHES.

K. MAGNETIC PARTICLE INSPECT USING CONTINUOUS FLORESENT METHOD WITH A MAGNETIZING CURRENT OF 800-1200 AMPERES IN A CIRCULAR AND LONGITUDINAL METHOD.

L. ~~NO INSPECTION~~ LOT SHALL CONSIST OF MORE THAN EIGHTY SPRINGS.

SPRING DATA:

OUTSIDE DIA SOLID, FOR ANY ONE COIL, NOT MORE THAN	14.120 INCHES
INSIDE DIA FREE, FOR ANY ONE COIL, NOT LESS THAN	11.480 INCHES
ASSEMBLED HEIGHT (BASIC)	22.500 INCHES
LOAD AT ASSEMBLED HEIGHT	2800 LBS MIN
SOLID HEIGHT, NOT MORE THAN	9.0 INCHES
DIA OF WIRE, CENTERLESS GRIND TO	1.035-.010 INCHES
FREE HEIGHT (APPROX)	45 INCHES
SPRING RATE (REF)	130 LBS/IN
NUMBER OF COILS, NOT LESS THAN	8.0 COILS
DIRECTION OF COILING	OPTIONAL

3. WHEN THE SPRING IS MOUNTED OVER A STANDARD RECOIL PISTON 11658913 WITH RING 8370368 AND COMPRESSED TO A HEIGHT OF 22.50 USING RETAINER SEAT 10887160 AND RESTRAINING THE SPRING ENDS FROM ROTATING, THE FOLLOWING REQUIREMENTS SHALL BE MET:

A. COILS MAY RUB ON AS MANY AS FOUR (4) ADJACENT PISTON SPLINES BUT MUST NOT TOUCH SPLINES DIAMETRICALLY OPPOSITE. STAGGER OF COILS TO BE LIMITED SO THAT THE SPRING WILL CLEAR A SWEEP GAGE CONCENTRIC WITH THE ASSEMBLY AND HAVING A RADIUS OF 7.12.

B. HARDNESS SHALL NOT BE GREATER THAN Rc52 AND CHECKED ACCORDING TO HARDNESS TEST PROCEDURE DRAWING D8448832.

PART NO. 3671112-2

MECHANICAL PROPERTIES						
		F7972995	8733343	TOLERANCES ON DECIMALS	ORIGINAL DATE OF DRAWING 9 APR 953	DEPT OF THE ARMY ROCK ISLAND ARSENAL, ROCK ISLAND, ILL. 61201
		F10916555	M87A1GM	MATERIAL SEE NOTE	WEP	SPRING, RECOIL
		F8710144	M97 GM			
		K10940274	M150 GM	HEAT TREATMENT SEE NOTE		F 19204 3671112
		F10854102	M116 GM			
		K10905448	M140 GM	FINAL PROTECTIVE FINISH SEE NOTE		SCALE 1/4
	SEE NOTE	NEXT ASSY	USED ON			
		APPLICATION				

Rev: M 1970

APPENDIX B

APPENDIX B

Snedecor's F Test
Variance Ratio Test

A Test for "The Internal Consistency of
a Single String of Measurements" *

Digital Computer Program by N. E. Hinriksson

Based on Equations and Discussions from References 3 and 4.

```
C-FOCAL,1969

01.10 A "ENTER NUMBER OF VALUES  ",N;A "ENTER NUMBER OF GROUPS  ",G
01*13 S P=0;S CF=0;S R=0;S B=0;S Q=N/G;F I=1,N;A X;D 2
 01.15 G 4.2

02.10 S T=T+X;S B=B+X↑2;I (I/Q-FITR(I/Q)) 2.2,2.3,2.2
02.20 S A=A+X;R
02.30 S A=A+X;S R=R+G*A↑2/N;S A=0;R

04.20 S CF=T↑2/N;S Z1=(R-CF)/(G-1);S Z2=(B-R)/(N-G);T !!!,%8.02
0 4.50 T "  SOURCE OF           SUMS OF    DEGREES OF          VARIANCE",!
04.60 T "  VARIATION           SQUARES    FREEDOM             ESTIMATE",!
04.70 T !,"BETWEEN SAMPLES ",R-CF,%8.0,G-1,"           ",%8.02,Z1,!
04.71 T "WITHIN SAMPLES   ",B-R,%8.0,N-G,"          ",%8.02,Z2,!
04.72 F I=1,40;T "-"
04.73 T !,"  TOTALS           ",B-CF,%8.0,N-1,"   F FACT",%8.02,Z1/Z2

05.10 S M=FSQT[(B-CF)/(N-1)]/FSQT(N/G);S AV=T/N
05.13 T !!,"AVERAGE",%8.04,AV,!,"WARNING LIMITS    "
05.15 T "LOWER",AV-2*M,"      UPPER",AV+2*M,!
05.19 T "ACTION LIMITS     LOWER",AV-3*M,"      UPPER",AV+3*M,!!
*
```

*From p. 7 reference 5.

APPENDIX B (Continued)

Air Quenched 5160-H
"F" Values for As-Wound Oiameters

Spring(s)	Number of Values	Number of Groups	Mean Square*	Degrees of Freedom*	Variance*	"F" Factor Calculated Value	"F" Factor Std @5% Level**
A	8	4	G 0.03 L 0.01	3 4	0.01 0.00	3.54	6.59
B	8	4	G 0.01 L 0.01	3 4	0.01 0.00	1.36	6.59
B	8	4	L 0.01 G 0.01	3 4	0.01 0.00	1.36	9.12
C	8	4	G 0.08 L 0.06	3 4	0.03 0.02	1.89	6.59
0	8	4	L 0.06 G 0.08	3 4	0.02 0.02	0.91	9.12
A-B	16	2	L 0.00 G 0.06	1 14	0.00 0.01	0.58	245
A-C	16	2	L 0.02 G 0.18	1 14	0.02 0.01	1.91	245
A-D	16	2	L 0.03 G 0.17	1 14	0.03 0.01	2.48	245
B-C	16	2	L 0.02 G 0.17	1 14	0.02 0.01	1.27	245
B-0	16	2	L 0.02 G 0.17	1 14	0.02 0.01	1.83	245
C-D	16	2	L 0.00 G 0.28	1 14	0.00 0.02	0.10	245
A-B- C-D	32	4	L 0.05 G 0.34	1 14	0.02 0.01	1.45	8.62

*Between Samples Value is given first and Within Samples Value is given second.
G = Greater, L = Lesser

**From p. 220 Reference 3.

APPENDIX C

APPENDIX C

Student's "t" Test

A Test for Difference in Averages*

Computer Program by N. E. Hinriksson

Based on Equations and Discussions from References 3 and 4.

```
C-FOCAL,1969

01.10 A %8.06,"NUMBER OF VALUES: FIRST GROUP  ",N1
01.20 A "NUMBER OF VALUES: SECOND GROUP ",N2
01.30 S A=0;S B=0;F I=1,N1;A X;S A=A+X;S B=B+X↑2
01.40 S S1=B-A↑2/N1;S A1=A/N1
01.50 S A=0;S B=0;F I=1,N2;A X;S A=A+X;S B=B+X↑2
01.60 S S2=B-A↑2/N2;S A2=A/N2
01.70 T !,"AVERAGE: FIRST GROUP ",A1,!,"AVERAGE: SECOND GROUP",A2,!
01.85 S Z=FABS(A1-A2)/FSQT(((N1+N2)*(S1+S2))/((N1*N2)*(N1+N2-2)))
0 1.90 T "STUDENT'S 'T' FACTOR ",Z,!
01.95 T "DEGREES OF FREEDOM   ",%6,N1+N2-2,!
*
```

*From p. 13 of reference 5.

APPENDIX C (Continued)

Air Quenched 5160-H
"t" Values for As-Wound Diameters

				"t" Factor	
Springs	Number of Values	Number of Groups	Degrees of Freedom	Calculated Value	Std @ 5% Level*
A-B	16	2	14	0.483	2.145
A-C	16	2	14	1.320	2.145
A-D	16	2	14	1.539	2.145
B-C	16	2	14	1.070	2.145
B-D	16	2	14	1.294	2.145
C-D	16	2	14	0.167	2.145

*From p. 217 of Reference 3.

APPENDIX D

APPENDIX O

As Quenched (18% Polymer) 5160-H

"F" Values for As-Wound Diameters

Spring(s)	Number of Values	Number of Groups	Mean Square*	Degrees of Freedom	Variance*	"F" Factor Calculated Value	"F" Factor Std @ 5% Level**
F	8	4	G 0.01 L 0.00	3 4	0.00 0.00	6.33	6.59
G	8	4	G 0.01 L 0.00	3 4	0.00 0.00	3.26	6.59
H	8	4	G 0.01 L 0.01	3 4	0.00 0.00	1.80	6.59
I	8	4	G 0.01 L 0.00	3 4	0.00 0.00	4.33	6.59
F	8	2	L 0.00 G 0.01	1 6	0.00 0.00	2.12	234
G	8	2	L 0.00 G 0.01	1 6	0.00 0.00	1.75	234
H	8	2	L 0.00 G 0.02	1 6	0.00 0.00	0.96	234
I	8	2	L 0.00 G 0.01	1 6	0.00 0.01	0.12	234
F-G	16	2	L 0.01 G 0.01	1 14	0.01 0.00	6.72	245
F-H	16	2	L 0.02 G 0.03	1 14	0.02 0.00	11.48	245
F-I	16	2	L 0.01 G 0.02	1 14	0.01 0.00	3.50	245
G-H	16	2	L 0.01 G 0.03	1 14	0.01 0.00	3.63	245
G-I	16	2	L 0.00 G 0.03	1 14	0.00 0.00	1.75	245
H-I	16	2	L 0.01 G 0.03	1 14	0.01 0.00	4.59	245
F-G-H-I	32	4	L 0.03 G 0.04	3 28	0.01 0.00	7.51	8.62

*Between Samples Value is given first and Within Sample Value is given second.
G = Greater, L = Lesser

**From p. 220 Reference 3.

APPENDIX D (Continued)

As Quenched (18% Polymer) 5160-H

"t" Values for As-Wound Diameters

				"t" Factor		
Springs	Number of Values	Number of Groups	Degrees of Freedom	Calculated Value	Std @ 5% Level*	
F-G	16	2	14	1.947	2.145	
F-H	16	2	14	3.250	2.145	A Difference
F-I	16	2	14	1.364	2.145	
G-H	16	2	14	1.773	2.145	
G-H	16	2	14	0.284	2.145	
H-I	16	2	14	1.857	2.145	
A-F	16	2	14	2.479	2.145	A Difference
B-G	16	2	14	3.340	2.145	A Difference
C-H	16	2	14	1.131	2.145	
D-I	16	2	14	0.086	2.145	
A,B,C,D-F,G,H,I	64	2	62	2.442	Between 1.95996 and 2.042	A Difference

*From p. 217 of Reference 3

APPENDIX E

Equations for Spring Built Height and Maximum Stress After Presetting

BY Walter Pape DATE ________

The following equations were derived to provide a method to determine the theoretical free height "h_f" of a spring prior to presetting. The equations should help any spring manufacturer avoid the trial and error method usually employed. Figure 1 shows the cross section of the spring wire and extent of torsional stress prior to yielding.

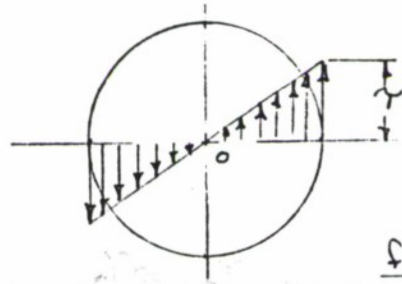


figure 1.

Figure 2 shows the extent of torsional stress assuming the material had an infinite elastic limit. The stress assuming an infinite elastic limit is illustrated by the dotted line and is designated τ_n. The actual torsional yield stress is designated τ_y and the diameter indicating the extent of yielding is "D_1".

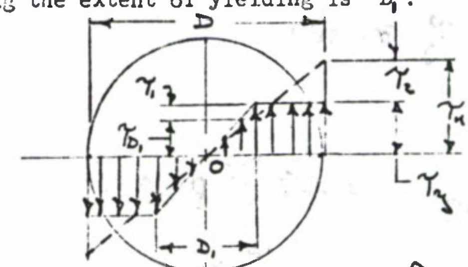


figure 2.

Assume a torque "Ty" is applied that is within the elastic limit "τ_y". Also assume a torque "Tn" is applied that is stressed to "τ_n".

(1.) Then also let Tn=Ty, since Tn is produced by the same coil radius and load.

$$T_n = \int_0^{D/2} \rho \tau_\rho \, dA$$

Where ρ = any distance outward from center o.
then, $\tau_\rho = \dfrac{2\rho \tau_n}{D}$, from $\dfrac{\tau_\rho}{\rho} = \dfrac{\tau_n}{D/2}$
and, $dA = 2\pi\rho \, d\rho$

Then

$$T_n = \int_0^{D/2} \rho \left(\frac{2\rho\tau_n}{D}\right) (2\pi\rho \, d\rho) = \frac{4\pi\tau_n}{D} \int_0^{D/2} \rho^3 d\rho$$

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Equations for Spring Built Height and Maximum Stress After Presetting

BY Walter Pape DATE

(2.) $$T_n = \frac{4\pi \tau_n \rho^4}{4D} \Big]_0^{D/2} = \frac{\pi \tau_n D^3}{16}$$

Also let,

$$T_y = \int_0^{D_1/2} \rho \tau_\rho \, dA + \int_{D_1/2}^{D/2} \rho \tau_y \, dA$$

Where $\tau_\rho = \frac{2\rho \tau_y}{D_1}$, from $\frac{\tau_\rho}{\rho} = \frac{\tau_y}{D_1/2}$

Then

$$T_y = \int_0^{D_1/2} \rho \frac{2\rho\tau_y}{D_1}(2\pi\rho \, d\rho) + \int_{D_1/2}^{D/2} \rho \, \tau_y (2\pi \rho \, d\rho)$$

or $$T_y = \frac{4\pi \tau_y}{D_1} \int_0^{D_1/2} \rho^3 d\rho + 2\pi \tau_y \int_{D1/2}^{D/2} \rho^2 d\rho$$

(3.) $$T_y = \frac{\pi \tau_y D_1^3}{16} + \frac{\pi \tau_y D^3}{12} - \frac{\pi \tau_y D_1^3}{12}$$

Then from equations 1, 2 and 3.

$$\frac{D^3}{16} = \frac{D_1^3}{16} + \frac{D^3}{12} - \frac{D_1^3}{12}$$

or

(4.) $$D_1^3 = D^3(4 - 3\,\tau_n/\tau_y)$$ or $$D_1 = D\sqrt[3]{4 - 3\frac{\tau_n}{\tau_y}}$$

Letting τ_1 = additive residual stress at $D_1/2$

τ_2 = negative residual stress at $D/2$

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Equations for Spring Built Height and Maximum Stress After Presetting

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And from the relation,

$$\frac{\tau_n}{D/2} = \frac{(\tau_y - \tau_1)}{D_1/2} \qquad \text{where, } \frac{D_1}{D} = \sqrt[3]{4 - 3\frac{\tau_n}{\tau_y}}$$

$$\tau_{D_1} = (\tau_y - \tau_1) = \frac{D_1}{D}\tau_n \qquad \tau_{D_1} = \tau_y - \tau_1$$

(5.) $$\tau_{D_1} = (\tau_y - \tau_1) = \tau_n \sqrt[3]{4 - 3\frac{\tau_n}{\tau_y}}$$

(6.) $$\tau_2 = \tau_n - \tau_y$$

Then assume the spring is loaded after presetting, the stress distribution is illustrated in figure 3.

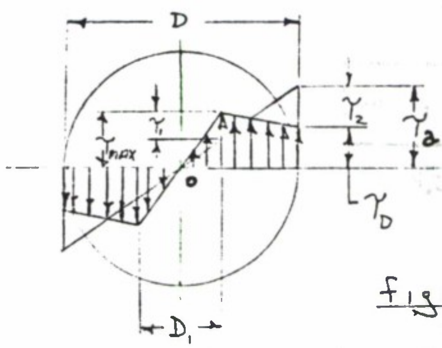

figure 3.

From the ratio

$$\frac{\tau_3}{D} = \frac{\tau_{max} - \tau_1}{D_1}$$

or

$$\tau_{max} = \tau_1 \pm \tau_3 \frac{D_1}{D}$$

Where τ_3 = Stress due loading based on deflection from new free height due to presetting

Then combining with equation 4,

(7.) $$\tau_{max} = \tau_1 + \tau_3 \sqrt[3]{4 - 3\frac{\tau_n}{\tau_y}}$$

and substituting eq 5. for τ_1

(8.) $$\boxed{\tau_{max} = \tau_y \sqrt[3]{4 - 3\frac{\tau_n}{\tau_y}}\left[\tau_n - \tau_3\right]} \qquad \text{for } \tau_n \leq \frac{4}{3}\tau_y$$

For stress "τ_D" at the surface of the wire after presetting and upon loading;

Equations for Spring Built Height
and Maximum Stress After Presetting

BY Walter Pape DATE

$\tau_D = \tau_y - \tau_2$

but by substituting eq 6. for τ_2

(9.) $\boxed{\tau_D = \tau_y - (\tau_n - \tau_y)}$

To determine the approximate built height "h_p" prior to presetting, we let "D_1" in equation (4) equal zero.

Then $\tau_n = \frac{4}{3}\tau_y$

But the stress "τ_n" which assumes infinite elastic limit could equal the stress rate "A" times the Wahl factor "K" multiplied by the built height "h_p" minus the solid height "h_s" or,

(10.) $\tau_n = AK\,(hp - hs)$

or $\boxed{hp = \frac{4\tau_y}{3AK} + \text{solid height}}$

for the M140 Mount Spring, known;

$\tau_y = 140\,000$ psi
A = 3735 psi/in
K = 1.115
hs = 9.5 in.

$$hp = \frac{4\,(140000)}{3\times3735\times1.115} + 9.5 = \underline{\underline{54.32}} \text{ inches.}$$

$$\tau_n = (54 - 9.5)\,AK = 185000 \text{ psi}$$

$$\tau_{max} = 140000 \sqrt[3]{4 - 3\frac{185000}{140000}}\left[185000 - 155000\right]$$

$$\tau_{max} = \underline{\underline{130000}} \text{ psi}$$

$$\tau_D = \underline{\underline{110000}} \text{ psi}$$

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The feasibility of using induction heating and concomitant quenching for hot winding large helical springs was established by the Research Directorate, Weapons Laboratory, WECOM. A full-scale experimental system was assembled, and M140 gun mount counterrecoil springs were coiled from three different materials. Springs with proper load-carrying capacity were produced from each of the materials. (U) (Williams, Samuel L.)

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